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BUDGETING FOR ENVIRONMENTAL CLEAN-UP OF ARMY BASES

by

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The United States Army obtained congressional approval in 1995 to close or realign 40 installations. These actions create a unique opportunity for the civilian communities surrounding the installations to reuse them to satisfy commercial or community needs. However, future reuse can be impeded by the need for environmental clean-up, which is an expensive business. The current clean-up cost estimate for 32 of the 40 installations is $1 billion from 1996 to 2001. This thesis develops an optimization model with a spreadsheet interface to help plan distribution of yearly environmental clean-up budgets. The model picks from supplied alternatives the clean-up level for each area within each installation that provides the greatest benefit for reuse while adhering to yearly budgets. To measure benefit this thesis develops a linear value model that quantifies the qualitative factors that provide benefit to a community. Extensive computational testing using Army and hypothetical data demonstrates how the model can help the Army effectively allocate their budget.

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BUDGETING FOR ENVIRONMENTAL CLEAN-UP OF ARMY BASES

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ABSTRACT

The United States Army obtained congressional approval in 1995 to close or realign 40 installations. These actions create a unique opportunity for the civilian communities surrounding the installations to reuse them to satisfy commercial or community needs. However, future reuse can be impeded by the need for environmental clean-up, which is an expensive business. The current clean-up cost estimate for 32 of the 40 installations is $1 billion from 1996 to 2001. This thesis develops an optimization model with a spreadsheet interface to help plan distribution of yearly environmental clean-up budgets. The model picks from supplied alternatives the clean-up level for each area within each installation that provides the greatest benefit for reuse while adhering to yearly budgets. To measure benefit this thesis develops a linear value model that quantifies the qualitative factors that provide benefit to a community. Extensive computational testing using Army and hypothetical data demonstrates how the model can help the Army effectively allocate their budget.

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EXECUTIVE SUMMARY

The United States Army obtained congressional approval in 1995 to close or realign 40 installations. These actions create a unique opportunity for the civilian communities surrounding the installations to reuse them to satisfy commercial or community needs. However, future reuse can be impeded by the need for environmental clean-up, which is an expensive business. The current clean-up cost estimate for 32 of the 40 installations is $1 billion from 1996 to 2001. The difficulty is achieving this goal with limited budgets: how should the Army allocate limited yearly budgets to the installations for environmental clean-up? Important decision criteria for an optimal allocation are the planned reuse of an installation, the benefit for the population around an installation, and the degree of pollution.

This thesis develops an elastic mixed integer linear programming model to help plan distribution of yearly environmental clean-up budgets. The goal of this model is to maximize the benefit, received from environmental clean-up which is constrained by yearly budgets. The model suggests a budget allocation by selecting clean-up options from supplied alternatives. The model contains two categories of clean-up alternatives: funding-stream options that contain user defined multi-year funding alternatives of which the model must pick only one and flexible options where the model has flexibility to pick both the year to start clean-up and the funding level per year.

To define benefit this thesis develops a linear value model that combines qualitative criteria, like reuse, clean-up actions, time, community assessment and population density into a quantitative measure of effectiveness. This value model can either assign different numbers (benefit values) to preferred consequences or the model can be a utility function, where the expected utility indicates relative desirability. The model uses a spreadsheet based input interface to stipulate the benefit values.

The optimization model is implemented using the General Algebraic Modeling System. The results of the model are presented numerically and graphically in MS-EXCEL.

Extensive testing of the model using both Army and hypothetical data shows the model produces a robust yearly budget allocation from 1996 to 2001 for all 32 installations in less than ten minutes. This budget allocation can provide guidance for the decision maker to find the most beneficial allocation of available yearly budgets.

I. INTRODUCTION

The United States Army obtained congressional approval in 1995 to close or realign 40 installations (see Figure 1 for installation locations) [United States Defense Base Closure and Realignment Commission, 1995]. These actions create a unique opportunity for the civilian communities surrounding the installations to reuse them to satisfy commercial or community needs. However, future reuse can be impeded by the need for environmental clean-up and cleaning up Army facilities is an expensive business: the current clean-up estimate for 32 of the 40 installations is one billion dollars from 1996 to 2001. This thesis develops an optimization model to help plan distribution of yearly environmental clean-up budgets. The model picks from supplied alternatives the clean-up level for each area within each installation that provides the greatest benefit for reuse while adhering to yearly budgets.

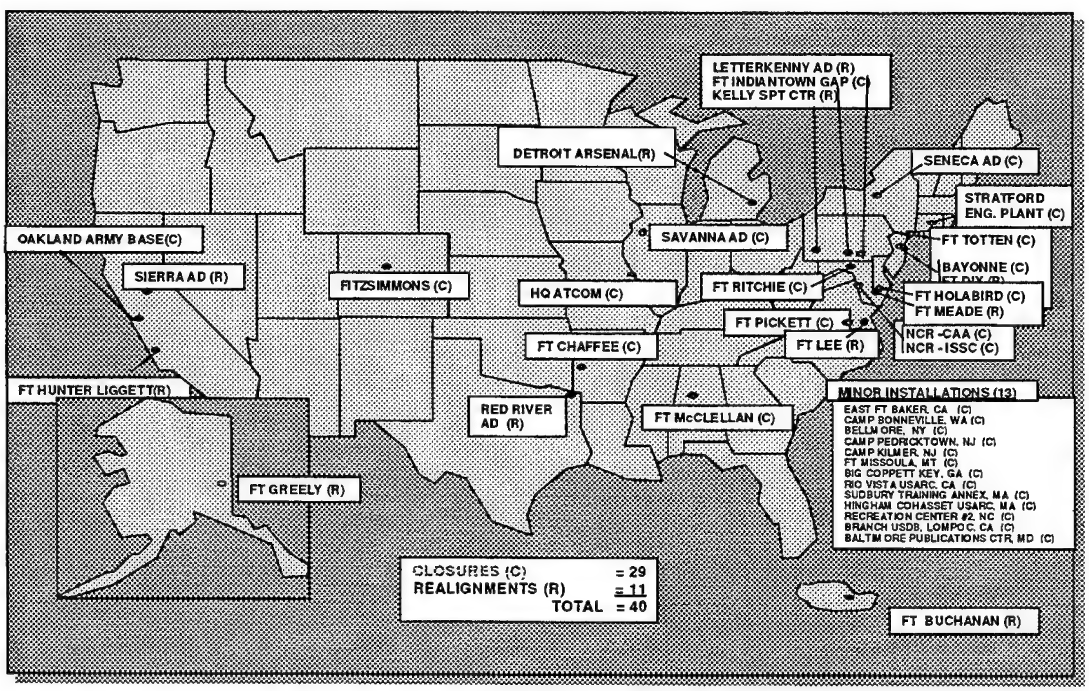

Figure 1. The 40 Army installations approved in 1995 for closure (C) or realignment (R). The estimated environmental clean-up cost for 32 of the installations is $1 billion over 6 years.

To prepare installations for closure or realignment, each closing installation forms a Base Realignment and Closure (BRAC) clean-up team that includes representatives from the Environmental Protection Agency (EPA) and the state regulatory agencies. Their task is to assess pollution and expedite installation clean-up and reuse. When environmental clean-up of a military installation (or a part of the installation) is completed or a clean-up remedy is operating successfully, the facility is transferred to the community. The goal is to start the reuse process early to increase public benefit [United States Defense Base Closure and Realignment Commission, 1995].

The difficulty is achieving this goal with limited budgets: how should the Army allocate limited yearly budgets to the installations for environmental clean-up? Important decision criteria for an optimal allocation are the planned reuse of an installation, the benefit for the neighboring population, and the degree of pollution.

A. ASPECTS OF ENVIRONMENTAL POLICY

Over the past few decades a major change has taken place between the United States and its relationship to the environment. Increasing levels of pollution lead to a new concern for nature and the environment. Since the National Environmental Policy Act of 1969 became law [Utton and Henning, 1973], the US government has increased its budget for environmental concerns. Currently the US spends more than two percent of its gross domestic product on environmental policy [Greenberg, 1995].

B. ENVIRONMENTAL CLEAN-UP IN THE MILITARY

An essential aspect of environmental clean-up is determining the level of pollution and the environmental hazards. The relative risk site evaluation framework pursued by the Department of Defense serves as a tool to assess relative risk at military sites [Office of the Deputy Under Secretary of Defense, 1994]. This framework provides guidance ensuring sites with a higher risk are considered first and more money is allocated for clean-up of military installations approved for closure or realignment.

The categories on the relative risk assessment are high, medium and low. Key factors that determine these qualitative assessment are:

- a contaminant hazard factor (CHF);
- a migration pathway factor (MPF); and
- a receptor factor (RF).

The contaminant hazard factor is a ratio whose numerator is the highest concentration of the contaminant in either groundwater, surface/soil or surface water/sediment. The denominator is a concentration standard for that contaminant that is risky for human health. If several contaminants exist in a media, the ratios from the individual contaminants are added. The CHF rating is considered significant when the ratio is greater than 100, moderate when it is between 2 and 100 and minimal when the ratio is less than 2.

The migration pathway factor reflects the ability of a contaminant to migrate. The MPF is categorized as evident (contaminants have moved), potential (no evidence of moving but contaminants might have mobile properties), or confined (contaminants have little or no potential to move).

Information about the present or future likelihood of receptors for each site is summarized as the RF. Only human receptors are considered for groundwater exposure. The RF is rated as identified (groundwater is a current source of drinking water), potential (groundwater is usable for drinking water, but not presently used) or limited (groundwater is not considered a source of drinking water) based on available information about a site.

The overall site risk is simply the highest rating from the CHF, MPF and RF. Figure 2 shows a summary of how the risk categories are determined.

These categories have an essential impact on the required clean-up level and consequently on an installation's budget allocation for environmental clean-up.

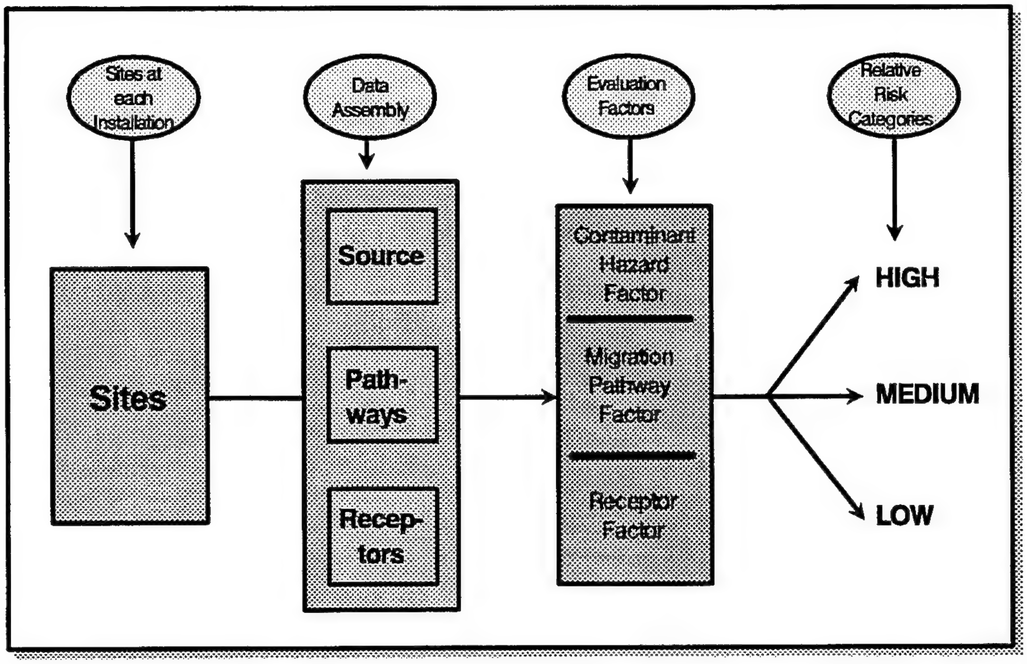

Figure 2. Relative Risk Site Evaluation Framework. The risk categories for each site are rated based on sources, pathways and human or ecological receptors in groundwater, surface water and surface soil. The evaluation factors for these three media provide an estimate of the risk categories. The higher the risk for a site, the higher the priority for environmental clean-up [Office of Deputy Under Secretary of Defense, 1994].

With information on risk assessment and risk categories, the clean-up cost can be estimated. A useful tool for environmental cost estimation is a program called "Remedial Action Cost Engineering and Requirements System (RACER)" [Delta Research Corporation, 1996]. This program can estimate the cost while taking into account both location and risk for all phases of remediation for some contaminators. The program categorizes the following forms of environmental pollutants: water pollution, groundwater pollution, toxic waste, soil erosion and chemical land pollution. To clean up installations with these forms of pollution, several clean-up actions can be considered. Table 1 shows a summary of the clean-up actions considered in this thesis. To provide a useful ordering, each installation is divided into four different areas:

1. Military area: includes headquarters buildings, technical buildings, vehicle sheds, parking lots, rifle ranges, parade grounds and administrative buildings;
2. Housing area: includes family housing, recreational grounds, exchange, gas stations and establishments for public life;
3. Training area: maneuver areas, training and exercise places etc.;
4. Impact areas: prohibited areas, live firing ranges, testing places etc.

Clean-Up Actions	Military Area	Housing Area	Training Area	Impact Area
Asbestos Removal	X	X		
USTS Removal	X	X	X	X
UXO Removal	X		X	X
Removal Actions	X	X	X	X
PCB Abatement	X	X	X	X
LBP Abatement	X	X	X	X
Soil Remediation	X	X	X	X
Radiation Remediation	X			X
Chemical Remediation	X		X	X
Garbage Disposal	X	X	X	X
Hazardous Waste Disposal	X		X	X
Septic/Medical Disposal	X	X		
Building Clean-up	X	X		
Landfill Clean-up	X		X	X
Water Treatment	X	X	X	X
Lead Contamination	X		X	X
Area Closures/Fencing/Clean-Up	X	X	X	X
Remedial Investigation/Surveys	X	X	X	X

Table 1. Clean-up actions potentially needed on different areas of a military installation. Removal actions summarizes the removal of drums, tanks, furnaces, oil/water separators, etc. (USTS is Underground Storage Tank Site; UXO is Unexploded Ordnance; PCB is Poly-chlorinated Biphenyl; and LBP is Lead Based Paint).

C. CIVILIAN REUSE OF MILITARY INSTALLATIONS

The planned civilian reuse of an installation or a part of an installation can play a significant role in budget allocation since the neighboring population benefits from the

decided reuse. Some factors influencing this benefit are [President's Economic Adjustment Committee, 1978]:

- employment (replacement of DOD civilian job losses);
- public uses (creating multipurpose design for former installations);
- highest and best use (various reuse plans for parcels and buildings);
- transportation access (new roads etc.);
- quality environment (performance standards); and
- an installation's image to the civilian community.

The reuse of an installation is influenced by the interest of the local communities in developing a reuse plan. Table 2 shows a summary of likely reuse possibilities taken from past uses of converted military installations [Department of Defense, 1990].

Reuse Possibilities	Military Area	Housing Area	Training Area	Impact Area
University	X	X	X	X
College	X	X	X	
Technical Institute	X	X	X	X
Office Industrial Park	X	X		
Office Industrial Plant	X		X	
Recreational Park			X	X
Housing Center	X	X		
Fire Station	X		X	
Sports Training Center	X	X	X	
Hotel Area	X	X		
Shopping Center	X	X		
Historical Site	X		X	X
Homeless Shelter	X	X		
Community Hospital	X	X	X	
Camp Ground			X	X
Rehabilitation Center	X	X	X	X
Retirement Community	X	X	X	X
Office Building	X			

Table 2. Summary of reuse possibilities for the 32 Army installations; X indicates a possibility for reuse. This table is hypothetically based on previous reuse at former military installations.

D. OUTLINE

Chapter II provides an overview of research related to this thesis. This overview is ordered into three main categories. The first presents operations research literature dealing with optimizing environmental clean-up. The second part describes related work on value model building and the third presents governmental guidance related to environmental clean-up. Chapter III discusses the development of the linear integer program to aid in environmental clean-up budget allocation. It describes the needed data and alternative models to evaluate measures of effectiveness. Chapter IV explains the model's computer implementation using the General Algebraic Modeling System (GAMS) [Brooke, Kendrick and Meeraus, 1992] and MS-EXCEL 5.0 [MICROSOFT Corporation, 1994]. It discusses the results of the computer implementation using currently available data. Chapter V presents conclusions and recommendations of how this model could be modified and applied to other environmental problems.

II. RELATED RESEARCH

There are many cases where operations research models and techniques have been used in environmental management. Bloemhof-Ruwaard, Van Beek, Hordijk and Van Wassenhove [1995] provide an overview of management issues associated with routing hazardous waste, locating sites for waste disposal and product recovery (how to handle products after consumer use, such as recycling, repair or reuse). Their discussion focuses on issues and provides some guidance on optimization but they do not present mathematical models.

ReVelle, Cohon and Shobrys [1991] present a mathematical model based on a network formulation for routing hazardous waste transportation. They explain a routing and siting model in detail and discuss their solutions based on the short-term problem of where to open away-from-reactor storage facilities during the 1980s to store spent fuel generated through 1989. The authors do not report any real-world use of their model.

An overview of optimization models used for environmental quality control is given by Greenberg [1995]. The focus of his study is to describe integrated models that deal with economic issues of environmental quality control. He explains basic terms and categorizes optimization models from the literature by air, land and water quality control. A main contribution of his paper is the annotated bibliography, which contains literature of models that represent various environmental aspects in connection with the economy.

Loucks, ReVelle and Lynn [1967] develop a linear programming model to minimize the cost for wastewater treatment within a river basin. They describe how to use biological and chemical laws as linear constraints within a linear program to determine minimum cost solutions. They illustrate their model using a hypothetical example. ReVelle and Ellis [1994] describe management models that deal with water and air quality using similar techniques presenting detailed mathematical models without presenting any real-world application of their models.

The problem of how to optimally allocate limited budgets for environmental clean-up of military installations is similar to the model described by Corbett, Debets and Van Wassenhove [1995]. These authors present an integer linear program to help allocate

budgets to maximize environmental effectiveness and economic efficiency. The model considers the decentralization of a central budget to local communities and regional authorities to clean up environmental sites. It also considers aspects of waste storage capacities and labor requirements for the clean-up projects. Finally they present two hypothetical examples to illustrate their model.

None of the models published so far deals with an optimal budgeting approach based on maximizing the benefit of reuse associated with environmentally cleaning sites. One difficulty with such a problem is how to stipulate a measure of effectiveness that adequately describes the benefit for reusing a military installation. Keeney [1992] provides guidance on how to quantify such an abstract MOE. He describes the role of values in a decision making process and how those values should be used to improve decision making. Furthermore, he gives ideas on how to build value models and discusses their uses, using management applications and value-focusing for everyday decisions.

Likewise, few models exist that describe environmental clean-up issues dealing with various methods to clean up polluted areas. An example is the RACER model which helps estimate cost for certain environmental clean-up actions. This means that clean-up methods have to be summarized in terms of cost using a particular action for a particular area. Clean-up methods are described in various papers [e.g., Bandy et al., 1987] that deal with environmental issues regarding reuse of military facilities.

Several government documents describe how to use environmental laws to indemnify contractors for clean-up [United States General Accounting Office, 1994]. This paper briefly shows mistakes made during cooperation between the U.S. Army and environmental contractors. Faults associated with determining the contractor's liability are demonstrated.

How to reuse closed installations is also described in a variety of official government documents. The President's Economic Adjustment Committee [1978 and 1990] show step-by-step strategies for communities to plan the reuse of formerly military installations. They describe planning objectives like employment and public use as well as development costs for military installations. Furthermore, they give examples of reuse possibilities of previously closed military installations.

The civilian reuse of former military installations from the economic point of view is presented in a study by the Department of Defense [1990]. This paper summarizes completed military installation projects from 1961 to 1990 comparing civilian job losses and new established jobs, caused by civilian reuse. For 97 military installations closed or realigned during this period 87,557 civilians lost their jobs while 163,685 new jobs were created. Finally, it presents current activities on these former military installations.

An impression of how environmental clean-up impacts the work of military personnel is shown in articles by Shellner [1992] and Haggerty [1992]. They provide reports of military organizations that are established at their installations to manage environmental clean-up before closing an installation. They describe problems that may arise during clean-up periods or while preparing an environmental impact study. Furthermore, they describe the tasks and responsibilities of military clean-up teams, such as disposal management teams, environmental service office and construction management.

Based on Keeney's approach as well as previous and present government studies, the model developed here uses easily determined subjective values to measure the benefit of reusing military facilities according to local communities in those particular areas. The issue is not the precision of these values but reasonably accurate and agreeable values for affected parties.

III. OPTIMIZATION MODEL FOR BUDGET ALLOCATION

A. CONCEPTUAL DESCRIPTION

Every military installation can be divided into several areas (e.g., housing, training, impact). Clean-up actions are established in each area, according to the degree of pollution and a timetable defined. Each action and each timetable has an associated cost and an associated benefit value used as a guide for budget allocation. The benefit value is based on the planned reuse and the population around the installation. The assignment of benefit values is subject to the decision maker's choice and his or her opinion of highly beneficial reuse.

The model contains two categories of clean-up possibilities for an action: funding-stream options that contain user-defined multi-year funding alternatives and flexible options where the model selects the beginning year and funding per year. The following examples illustrate the two categories of options.

As an example of the funding-stream option, suppose cost estimates (in thousands of dollars) for water treatment on an installation are as follows:

Year	1996	1997	1998	1999	2000	2001
Option 1	80	70	80	90	50	50
Option 2	160	170	170	0	0	0
Option 3	100	90	200	200	0	0

Option 1 needs 6 years to finish clean-up with an undiscounted total of $420,000. Option 2 indicates a faster method for the same clean-up in 3 years with a total of $500,000 and option 3 needs four years a total cost of $590,000. The model has the choice between these three options and must pick only one. Having selected one, the yearly costs are known.

As an example of a flexible option, suppose that asbestos removal can be conducted in any year; it requires only one year to conduct and the following represents the cost (in thousands of dollars) of removal in any year:

Year	1996	1997	1998	1999	2000	2001
	150	160	175	185	200	215

The flexible option assumes any portion of this yearly defined cost can be paid in any year as long as it is above some user-defined minimum in the initial year. If the models picks, for example, 50% clean-up level in year 1996, 25% in 1997 and 25% in 1998, the total cost for removing asbestos is $75,000 + $40,000 + $43,750 = $158,750.

Based on the cost data for the clean-up actions, the benefit value assignment and the population impact, the decision is how much money to allocate each year to clean up each area on each military installation. In other words, what option to pick for each area in order to maximize the benefit for neighboring populations. These options must be determined to adhere to yearly minimum and maximum individual installation budgets as well as a yearly total budget across all installations.

It is assumed that there is a minimum cost for environmental training, administration and clean-up preparation to preserve the present environmental status of each installation, regardless of the clean-up itself. It is further assumed for flexible options that when environmental clean-up starts in a year, clean-up has to be continued in the following years until a minimum clean-up level is obtained. There is also a pre-defined minimum level of clean-up for flexible options that must be achieved in the year clean-up starts

The overall results describe, how to distribute the given yearly budget on all installations in order to maximize the benefit for the local communities according to the reuse of these military installations.

B. OPTIMIZATION MODEL

The above problem is formulated as an elastic mixed integer linear program, called BAEC (Budget Allocation of Environmental Clean-Up). The elastic variables ensure that the budget levels are violated when they cannot be satisfied.

Indices

i	installations;
j	areas to be cleaned up;
k	clean-up actions;
o	funding-stream options; and
t, t'	year.

Index Sets

SELECT	area j, installation i and clean-up action k combinations with funding-stream options o; and
SEL_{ik}	areas with funding-stream options for clean-up action k at installation i.

Data

$COST_{ijkt}$	cost to clean up area j of installation i by action k during year t using a flexible option;
$SCOST_{ijkot}$	cost to clean up area j of installation i by action k with funding-stream option o during year t;
$MINCOST_{it}$	fixed cost to administer clean-up on installation i in year t;
BG_t	budget available to clean up all installations in year t;
$LBUDGET_{it}$	minimum amount of money to spend on installation i in year t;
$UBUDGET_{it}$	maximum amount of money to spend on installation i in year t;

$BVALUE_{ijkt}$	benefit value assigned to area j of installation i if it is cleaned up using action k in year t using a flexible option;
$SBVALUE_{ijkot}$	benefit value assigned to area j of installation i in year t if it is cleaned up using action k with funding-stream option o;
$MININIT_{ijt}$	minimum initial clean-up level on area j of installation i if started in year t using a flexible option;
$MINLEVEL_{ij}$	minimum clean-up level to be reached on area j of installation I using a flexible option;
POP_i	population around installation i;
POPWT	a weight associated with the desire to influence spending based on the population around installations;
$PENBG_t$	penalty for violating constraint on total budget in year t;
$PENLBUDGET_t$	penalty for violating an installation's lower budget limit in year t; and
$PENUBUDGET_t$	penalty for violating an installation's upper budget limit in year t.

Variables

$LEVEL_{ijkt}$	level of clean-up action k for area j of installation i in year t for a flexible option (a number between 0 and 1);
Y_{ijkt}	1 if the clean-up of area j on installation i by action k starts in year t using a flexible option;
X_{ijko}	1 if clean-up of area j on installation i by action k done by funding-stream option o;
$EUBUDGET_{it}$	amount above installation i's upper budget limit in year t;
$ELBUDGET_{it}$	amount below installation i's lower budget limit in year t; and
EBG_t	amount above the total budget limit in year t.

Formulation

MAX

$$\sum_{(i,j,k)\notin SELECT} \sum_{t} (BVALUE_{ijkt} * LEVEL_{ijkt}) + \sum_{(i,j,k)\in SELECT} \sum_{o} X_{ijko} \sum_{t} SBVALUE_{ijkot}$$

$$-\sum_{i} (\frac{POPWT}{POP_i} * (\sum_{t} MINCOST_{it} + \sum_{k} \sum_{j\notin SEL_{ik}} \sum_{t} (COST_{ijkt} * LEVEL_{ijkt})$$

$$+\sum_{k} \sum_{j\in SEL_{ik}} \sum_{o} \sum_{t} (SCOST_{ijkot} * X_{ijko}))) \qquad (1)$$

$$-\sum_{i} \sum_{t} PENLBUDGET_t * ELBUDGET_{it} - \sum_{i} \sum_{t} PENUBUDGET_t * EUBUDGET_{it}$$

$$-\sum_{t} PENBG_t * EBG_t$$

S.T.

$$\sum_{k} \sum_{j\notin SEL_{ik}} (COST_{ijkt} * LEVEL_{ijkt}) + \sum_{k} \sum_{j\in SEL_{ik}} \sum_{o} (SCOST_{ijkot} * X_{ijko}) + MINCOST_{it} \le UBUDGET_{it} + EUBUDGET_{it} \qquad \forall i,t \qquad (2)$$

$$\sum_{k} \sum_{j\notin SEL_{ik}} (COST_{ijkt} * LEVEL_{ijkt}) + \sum_{k} \sum_{j\in SEL_{ik}} \sum_{o} (SCOST_{ijkot} * X_{ijko}) + MINCOST_{it} \ge LBUDGET_{it} + ELBUDGET_{it} \qquad \forall i,t \qquad (3)$$

$$\sum_{(i,j,k)\notin SELECT} (COST_{ijkt} * LEVEL_{ijkt}) + \sum_{(i,j,k)\in SELECT} \sum_{o} (SCOST_{ijkot} * X_{ijko}) + \sum_{i} MINCOST_{it} \le BG_t + EBG_t \qquad \forall t \qquad (4)$$

$$\sum_{t} LEVEL_{ijkt} \le 1 \qquad \forall (i,j,k) \notin SELECT \qquad (5)$$

$$MININIT_{ijt} * Y_{ijkt} \le \sum_{t'=1}^{t} LEVEL_{ijkt'} \qquad \forall (i,j,k) \notin SELECT, t \qquad (6)$$

$$LEVEL_{ijkt} \le Y_{ijkt} \qquad \forall (i,j,k) \notin SELECT, t \qquad (7)$$

$$\sum_t LEVEL_{ijkt} \geq MINLEVEL_{ij} \qquad \forall (i,j,k) \notin SELECT \qquad (8)$$

$$\sum_o X_{ijko} = 1 \qquad \forall (i,j,k) \in SELECT \qquad (9)$$

$$LEVEL_{ijkt} \geq 0 \qquad \forall (i,j,k) \notin SELECT, t \qquad (10)$$

$$Y_{ijkt} \in \{0,1\} \qquad \forall (i,j,k) \notin SELECT, t \qquad (11)$$

$$X_{ijko} \in \{0,1\} \qquad \forall (i,j,k) \in SELECT, o \qquad (12)$$

The objective function term

$$\sum_{(i,j,k) \notin SELECT} \sum_t \left(BVALUE_{ijkt} * LEVEL_{ijkt} \right) + \sum_{(i,j,k) \in SELECT} \sum_o X_{ijko} \sum_t SBVALUE_{ijkot}$$

maximizes the overall benefit of clean-up. The benefit values for funding-stream options allow yearly benefit values to be assigned. However, the benefit value for flexible options in any year reflects the fraction of clean-up in that year. Minimum initial clean-up levels ($MININIT_{ijt}$) can lessen the impact of this linear assumption. The second objective function term

$$\sum_i \left(\frac{POPWT}{POP_i} * \left(\sum_t MINCOST_{it} + \sum_k \sum_{j \notin SEL_{ik}} \sum_t \left(COST_{ijkt} * LEVEL_{ijkt} \right) \right.\right.$$
$$\left.\left. + \sum_k \sum_{j \in SEL_{ik}} \sum_o \sum_t \left(SCOST_{ijkot} * X_{ijko} \right) \right) \right)$$

encourages spending in more populated areas. The remaining part of the objective function provides penalties for violating the budget requirements. Constraint (2) ensures that the yearly money spent to clean up an installation does not exceed an installation specified upper limit and constraint (3) gives a lower limit. The total yearly budget across all installations is limited by constraint (4). Constraint (5) ensures that the level for each flexible option on an installation can not exceed 100%. Constraint (6) ensures that a minimum initial threshold must be satisfied before starting clean-up in year t for each

flexible option. Constraint (7) ensures that the clean-up level can only have a value when clean-up is initiated. Constraint (8) ensures that the minimum clean-up level for flexible options is reached at the end of the last clean-up period. Constraint (9) ensures only one funding-stream option is selected.

C. MEASURES OF EFFECTIVENESS

There is a need for a quantitative measure for the benefit of cleaning up a military installation. The easiest way to develop a benefit value is simply to assign a value to that installation, based on its planned civilian reuse or any other criteria. However this simple way of prioritizing objectives may lead to a budget allocation inconsistent with the decision maker's objective.

A more sophisticated way to evaluate benefit values is using a value model that quantifies objectives [Keeney, 1992]. A benefit value for environmental clean-up contains the following quantitative and qualitative relationships:

1. The closure of an installation results in a higher benefit value than realignment of a military installation;
2. Different planned civilian reuse possibilities for an installation/area result in different benefit values;
3. The population living around an installation influences the benefit value. An area with a higher population obtains a higher benefit;
4. If the local community is interested in reusing a military installation, the population obtains more benefit;
5. Different clean-up actions obtain different values of benefit. An intensive clean-up action results in higher benefit; and
6. The earlier the environmental clean-up started and finished, the higher the benefit.

The last two relationships are highly dependent on the risk assessment evaluated by the Relative Risk Site Framework. For further discussion, these six relationships are described as:

1. activity;
2. reuse;
3. population;
4. community assessment;
5. clean-up action; and
6. time.

Using these relationships, which all seem to be quantitatively measurable, a value model can be developed. This value model can either assign different numbers (values) to preferred consequences or the model can be a utility function, where the expected utility indicates relative desirability.

Because these relationships don't contain uncertainties, the need for a nonlinear utility function is not obvious [Keeney, 1992]. The additive utility function used in this thesis is of the following form for both the BVALUE and the SBVALUE:

$$BVALUE_{ijkt} = \sum_n k_n * B_n \qquad \forall i, j, k, t \text{ ; and}$$

$$SBVALUE_{ijkot} = \sum_n k_n * B_n \qquad \forall i, j, k, o, t \text{ ;}$$

where $\sum_n k_n = 1$;

k_n: scaling factor for value n; and

B_n: value for criterion n.

Table 3 shows the summary and the assignment of the B_i's and k_i's to the appropriate criteria.

	Criterion	B_n	k_n
1	activity	B_1	k_1
2	reuse	B_2	k_2
3	population	B_3	k_3
4	community assessment	B_4	k_4
5	clean-up action	B_5	k_5
6	time	B_6	k_6

Table 3. Assignment of values and scaling to the different criteria.

This model can assign more than one reuse possibility to an area of a military installation. The following examples clarifies the use of this value model when more than one possible reuse exists.

Example 1

Values assigned to the different criteria:

1. closure: 10
   realignment: 5

2. university: 30
   lodging: 10
   business offices: 25
   industrial parks: 35
   recreational area: 20

3. < 10,000: 5
   10K - 50K: 10
   > 50K: 20

4. no interest: 0
   low interest: 5
   high inter.: 10

5. building clean-up: 20
   garbage disposal: 25
   chemical remediation: 25

6. year 1: 5
   year 2: 4
   year 3: 3
   year 4: 2
   year 5: 1

Scaling factors:

k_1=0.1 k_2=0.4 k_3=0.05 k_4=0.1 k_5=0.3 k_6=0.05

Criteria: Installation is closed/training area becomes recreational area/ pop < 10K/low interest of community/garbage disposal/value for year 2

$BVALUE_{ij22} = 17.45$

Example 2

Values and scaling factors unchanged.

Criteria: Installation is realigned/housing area becomes lodging and business office/pop > 50K/high interest of community/chemical remediation/value for year 3

$BVALUE_{ij23} = 24.15$

Obviously the values for all criteria are subjective as well as their scaling factors. It is the decision maker's choice to quantify these values and factors.

Another way of assigning values to the benefit of environmental clean-up is the use of an analytic hierarchy process (AHP) [e.g., Marshall and Oliver, 1995]. The idea behind AHP is to rank the possible outcomes of each attribute/criterion by preference. The least preferred level of each attribute receives the value 1.0. Using the system of pairwise comparison, the levels of all criteria relative to the least preferred criterion are determined. Finally all the criteria are combined in a logical manner:

$$V(X) = \sum_i a_i * v_i(x_i)$$

with x_i : criterion i;

$v_i(x_i)$: level of criterion i ; and

a_i = value/unit of criterion i.

The following example demonstrates the results of AHP in comparison to the previously described value model.

Example:

Installation	Activity	Reuse	Population	Assessment	Clean-Up Action	Year
Fort A	Close	Technical Institute	40,000	High Interest	Action 1	1997
Fort B	Realign	Recreational Park	2,000	High Interest	Action 2	2000
Fort C	Close	Housing Center	77,000	High Interest	Action 1 Action 2	1998

Table 4. Data for three hypothetical military installations.

1. Definition of a_i:

Activity is 1.5 times as important as year ($a_1 = 1.5$);

Reuse is 4.0 times as important as year ($a_2 = 4.0$);

Population is as important as year ($a_3 = 1.0$);

Assessment is 1.2 times as important as year ($a_4 = 1.2$);

Clean-up action is 3.5 times as important as year ($a_5 = 3.5$); and

Year ($a_6 = 1.0$).

2. Preference Statements:

Closure is preferred 2.0 over realignment;

Technical Institute is preferred 1.1 over Recreational Park;

Housing Center is preferred 1.05 over Recreational Park;

Higher population is preferred 1.05 over lower population;

Action 1 is preferred 1.2 over action 2;

Action 1 and action 2 are preferred 1.6 over action 1; and

Earlier clean-up is preferred 1.2 over late clean-up.

3. Results

Installation	$a_1 = 1.5$	$a_2 = 4.0$	$a_3 = 1.0$	$a_4 = 1.2$	$a_5 = 3.5$	$a_6 = 1.0$	Value
Fort A	2.00	1.10	1.05	1.00	1.00	1.44	**14.59**
Fort B	1.00	1.00	1.00	1.00	1.30	1.00	**13.25**
Fort C	2.00	1.05	1.10	1.00	1.60	1.20	**16.30**

Table 5. Resulting values for three hypothetical installations. The results indicate the preference (ranks) for the different installations.

The disadvantage of this model is that every outcome has to be compared with the least preferred outcome of the same attribute. This can get confusing, when there is a large number of outcomes within an attribute category. Furthermore these values represent ranks, not quantitative and qualitative benefit values. Depending on the number of possible outcomes (BVALUE's), the range may be very large.

Another disadvantage is the flexibility of these subjective measures. The decision maker has to compare the levels of attributes to the least preferred attribute in order to obtain his or her desired value scheme. Again the number of comparisons might cause confusion and not clarity to the user of the model.

Benefit value models are not perfect. As Corbett, Debets and Van Wassenhove [1995] stated in their article, the issue is not to obtain a precise benefit value but rather to find a reasonably accurate value that is easy to determine and verify for the decision maker.

IV. COMPUTER IMPLEMENTATION AND RESULTS

A. DATA

The data required for the model is:

- subjective data on benefit values and minimum clean-up levels;
- cost and budget data; and
- population.

Unfortunately, not all data is readily available. The following describes the data that is available and what assumptions are made for unknown data.

The population living around an installation is assumed constant over the six years and is primarily the population within 10 to 15 miles from an installation. An exception is made if an installation is in a larger city (e.g., Detroit), the total population of the city is considered in the data set, although it may exceed 15 miles. Population data are easily obtained using the above method from Evinger [1991], Army Times [1995], U.S. Gazetteer [1995] and U.S. Census Bureau [1995]. An estimate of the population benefitting from the reuse is a more appropriate value but is not available.

This thesis assumes five clean-up actions that have funding-stream options. These actions are USTS removal, PCB abatement, LBP abatement, soil remediation and water treatment. For each of these clean-up actions three clean-up options are assumed: option 1 is a cheap clean-up option that takes several years to finish; option 2 is a more expensive and fast option; and option 3 is an expensive option that is the most effective but takes longer than option 2.

The minimum costs $MINCOST_{it}$ come from official cost estimates provided by the Army's Base Realignment and Closure Office (BRACO) for 1996 and 1997. For the remaining years the $MINCOST_{it}$ are hypothetically based on the provided data.

The total yearly budget for all installations and the maximum amounts of money to spend on an installation are provided by BRACO. The minimum amount of money to spend is assumed to be a percentile of the upper limit. The default is 5%.

The minimum clean-up level $MINLEVEL_{ij}$ describes the level of environmental clean-up that has to be reached at the end of the six year period for flexible options. It should be dependent on the risk assessment obtained through the relative risk site evaluation framework. This minimum clean-up level is described by a real number between 0 and 1. The default values used in this thesis are:

- High Risk Category: 0.9;
- Medium Risk Category: 0.6; and
- Low Risk Category: 0.3.

The decision maker is able to change these values.

The minimum initial clean-up level $MININIT_{ijt}$ describes the level of environmental clean-up that has to be reached in the first year of any flexible option. It is assumed that the minimum initial clean-up level is based on the available yearly budget and the desired ending level. Assuming a linear relationship of initial clean-up level and time, the following equation determines $MININIT_{ijt}$.

$$MININIT_{ijt} = \frac{LBUDGET_{it}}{UBUDGET_{it}} + \left(\frac{MINLEVEL_{ij} - (LBUDGET_{it} / UBUDGET_{it})}{T-1} \right) * t \qquad \forall i, j, t$$

where t = 0,1,...,T-1; (e.g., t = 1996,1997,...,2001);

and T>1 is the number of years, clean-up is conducted at area j of installation i.

If T = 1, $MININIT_{ijt} = MINLEVEL_{ij} \qquad \forall i, j, t.$

An example of this relationship is shown in Figure 3.

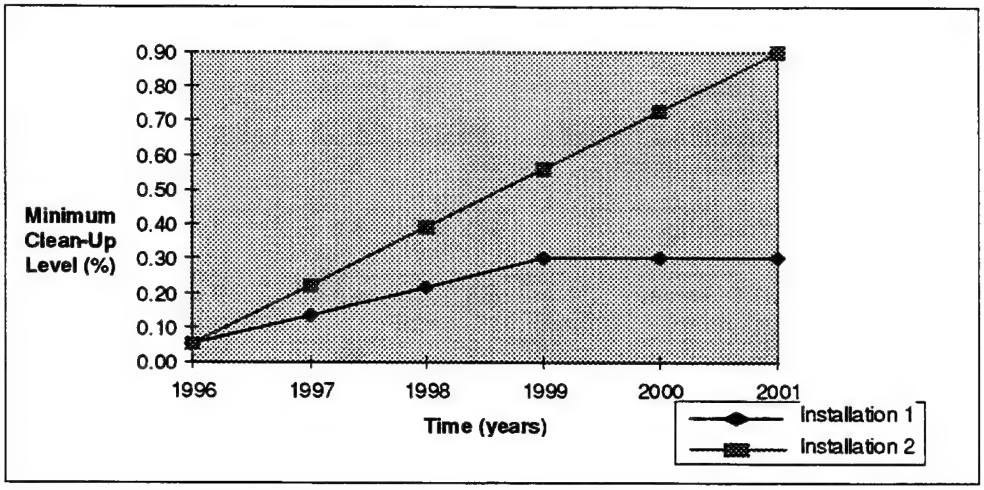

Figure 3. The minimum clean-up level to be reached at the end of every year; Installation 1 stops clean-up actions in 1999 - the level remains constant.

B. DATA INPUT

Very little cost data was available from 1998 to 2001 and therefore values shown in the next tables for these years are hypothetical. In addition, the risk assessment is hypothetical.

For easy access, all data enters via a MS-EXCEL 5.0 spreadsheet [MICROSOFT® Corporation, 1994]. The unchanging data are protected within the MS-EXCEL-workbook. The changing data are marked in a gray color. Default values are provided for all data, either changing or unchanging. The default filename for this workbook is 'BUDGET.XLS'. We show data required for the model as it appears in the workbook.

The first sheet of the workbook is called 'Input'. It provides the user with information about the six described criteria and their weight factors used to produce the benefit values. Table 6 shows the top part of the worksheet, listing the six criteria and the user-defined values (the different values are shown below). The decision maker can change these values but should ensure their sum equals one.

Criteria For Each Installation/Area	Value	Weight Factor		
1. Closure/Realignment	**B1**	**K1**	K1=	0.1
2. Reuse Possibility	**B2**	**K2**	K2=	0.4
3. Population Around Installation	**B3**	**K3**	K3=	0.05
4. Assessment of Community	**B4**	**K4**	K4=	0.1
5. Clean-Up Action	**B5**	**K5**	K5=	0.3
6. Year	**B6**	**K6**	K6=	0.05

Table 6. The six criteria and the default values for their weight factors.

Below this data field are the input matrices for the benefit values for the six criteria and the setting for the lower budget limit.

Values for B1	
Closure	10
Realignment	5

Values for B2		
1	University	30
2	College	25
3	Technical Institute	25
4	Office Industrial Park	35
5	Office Industrial Plant	35
6	Recreational Park	20
7	Housing Center	25
8	Fire Center	15
9	Sports Training Center	20
10	Hotel Area	15
11	Shopping Center	20
12	Historical Site	25
13	Homeless Shelter	10
14	Community Hospital	30
15	Camp Ground	20
16	Rehabilitation Center	15
17	Retirement Community	20
18	Office Building	30
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		

Values for B3	
< 10,000	5
10,000-50,000	10
> 50,000	20

Values for B4	
no interest	0
low interest	5
high interest	10

Values for B6	
1996	6
1997	5
1998	4
1999	3
2000	2
2001	1

Values for B5		
1	Asbestos Removal	50
2	USTS Removal	35
3	UXO Removal	40
4	Removal Actions	30
5	PCB Abatement	25
6	LBP Abatement	40
7	Soil Remediation	35
8	Radiation Remediation	50
9	Chemical Remediation	35
10	Garbage Disposal	25
11	Hazardous Waste Disposal	50
12	Septic/Medical Disposal	40
13	Building Clean-up	30
14	Landfill Clean-up	30
15	Water Treatment	40
16	Lead Contamination	45
17	Area Closures/Fencing	20
18	Remedial Investigation/Surveys	35

Values for Options of B5		
1	Option 1	20
2	Option 2	30
3	Option 3	40

LBUDGET=	0.05	*	UBUDGET

Table 7. Input data fields for benefit values B_1 to B_6, including the values for the clean-up options and the setting for the lower budget limit.

The decision maker can enter further reuse possibilities and their values in fields 19 to 28 under values for B_2 as follows:

- Fields 19/20: reuse at military area;
- Fields 21/22: reuse at housing area;
- Fields 23/24: reuse at training area;
- Fields 25/26: reuse at impact area; and
- Fields 27/28: reuse on all areas.

As soon as the user enters appropriate values, the spreadsheet routine starts recalculating the resulting 'BVALUE' matrix.

The next sheet (titled 'Info1') provides the user with information about the 32 military installations, whether they are approved for closure or realignment (Column 'ACT'), population data and the assessment of the community. To make changes in the community assessment column, the decision maker has to use capital letters 'H' for high community reuse interest, 'L' for low interest and 'N' for no interest. For approved closure or realignment he or she has to use capital letters 'C' and 'R' respectively. These cells are automatically calculated by MS-EXCEL after the user has made changes in the appropriate gray cells or on the 'Input' sheet.

INSTALLATION	STATE	ACT	Population	Community Assessment	Value for B1	Value for B3	Value for B4
Fort McClellan	Alabama	C	40,000	H	10	10	10
Fort Greely	Alaska	R	2,000	H	5	5	10
Fort Chaffee	Arkansas	C	77,000	H	10	20	10
Branch US Disciplinary Barracks Lompoc	California	C	38,000	N	10	10	0
East Fort Baker	California	C	230,000	N	10	20	0
Oakland Army Base	California	C	373,000	H	10	20	10
Rio Vista ARC	California	C	3,300	N	10	5	0
Sierra Army Depot	California	R	3,300	H	5	5	10
Fitzsimons Army Medical Center	Colorado	C	222,000	H	10	20	10
Stratford Army Engine Plant	Connecticut	C	50,000	H	10	10	10
Big Coppitt Key	Florida	C	27,000	N	10	10	0
Savanna Army Depot Activity	Illinois	C	4,000	H	10	5	10
Fort Holabird	Maryland	C	74,000	L	10	20	5
Fort Ritchie	Maryland	C	37,000	H	10	10	10
Hingham Cohasset	Massachusetts	C	580,000	N	10	20	0
Sudbury Training Annex	Massachusetts	C	580,000	N	10	20	0
Detroit Arsenal	Michigan	R	1,030,000	H	5	20	10
Fort Missoula	Montana	C	43,000	L	10	10	5
Bayonne Military Ocean Terminal	New Jersey	C	680,000	H	10	20	10
Camp Kilmer	New Jersey	C	27,000	N	10	10	0
Camp Pedricktown	New Jersey	C	14,000	N	10	10	0
Fort Dix	New Jersey	R	14,000	H	5	10	10
Bellmore Logistics Activity	New York	C	17,000	N	10	10	0
Fort Totten	New York	C	750	H	10	5	10
Seneca Army Depot	New York	C	34,000	H	10	10	10
Recreation Center #2, Fayetteville	North Carolina	C	76,000	L	10	20	5
Kelly Support Center	Pennsylvania	R	370,000	H	5	20	10
Letterkenny Army Depot	Pennsylvania	R	22,000	H	5	10	10
Fort Buchanan	Puerto Rico	R	427,000	H	5	20	10
Red River Army Depot	Texas	R	15,000	H	5	10	10
Fort Pickett	Virginia	C	9,000	H	10	5	10
Camp Bonneville	Washington	C	500	N	10	5	0

Table 8. Information field for closure or realignment, population and community assessment for all 32 military installations.

The sheet 'Info2' requires detailed input for planned installation reuse. This sheet is based on known reuse or general knowledge about reuse opportunities. The decision maker has to assign the number '1' in the appropriate gray colored data cell if it represents

a potential reuse. Non-assignments indicate an empty cell. The benefit values on the far right of the sheet are calculated automatically.

'Info3' (not shown) has the same structure as 'Info2'. It allows the decision maker to input needed clean-up methods on a military installation. As before, the number '1' indicates, that a clean-up action is needed on an installation.

The following sheet, titled 'Values' (not shown) provides a summary of the previous sheets based on the users input and decisions. All values are updated automatically due to changes in the previous sheets.

The worksheet 'Risk' (Table 10) gives the decision maker the opportunity to input the results of the risk assessment from the relative risk site evaluation for each area on every installation. The input is done with capital letters 'H' for high risk, 'M' for medium risk or 'L' for low risk. The blank cells indicate, that these areas do not exist on a military installation.

FACILITY	STATE	Reuse																												Values for B2			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Area	Area 2	Area 3	Area 4
Fort McClellan	Alabama	1			1				1					1																80	75	0	0
Fort Greely	Alaska		1		1		1																							60	60	20	20
Fort Chaffee	Arkansas						1																							0	0	20	20
Branch US Disciplinary Barracks Lompoc	California			1									1																	50	25	25	0
East Fort Baker	California					1				1																				35	55	20	55
Oakland Army Base	California				1				1																					50	35	0	0
Rio Vista ARC	California						1				1	1																		15	35	20	20
Sierra Army Depot	California					1		1																						35	60	0	35
Fitzsimons Army Medical Center	Colorado									1				1																0	30	20	20
Stratford Army Engine Plant	Connecticut		1												1															55	25	0	0
Big Coppitt Key	Florida	1														1	1													45	45	20	20
Savanna Army Depot Activity	Illinois			1	1																									60	60	0	0
Fort Holabird	Maryland					1	1						1																	60	35	45	55
Fort Ritchie	Maryland												1					1	1											55	20	45	20
Hingham	Massachusetts											1					1													15	35	0	0
Sudbury Training Annex	Massachusetts			1				1			1			1			1													55	90	0	0
Detroit Arsenal	Michigan												1																	25	0	25	0
Fort Missoula	Montana								1																					15	0	0	0
Bayonne Military Ocean Terminal	New Jersey								1																					15	0	0	0
Camp	New Jersey									1	1																			15	35	20	20
Camp Pedricktown	New Jersey											1																		0	20	0	0
Fort Dix	New Jersey				1	1											1													85	85	0	35
Bellmore Logistics Avtivity	New York																1													15	15	0	0
Fort Totten	New York												1	1																25	10	25	0
Seneca Army Depot	New York	1	1																											55	55	0	0
Recreation Center #2, Fayetteville	North Carolina			1				1																						25	50	0	0
Kelly Support Center	Pennsylvani						1																							0	0	20	20
Letterkenny Army Depot	Pennsylvani									1	1				1	1			1											75	35	40	40
Fort Buchanan	Puerto Rico				1	1			1																					85	70	0	35
Red River Army Depot	Texas			1				1																						25	50	0	0
Fort Pickett	Virginia											1			1															30	20	0	0
Camp Bonneville	Washington						1			1				1																0	30	40	40

Table 9. 'Info2:' the reuse matrix and the appropriate benefit values for each area on each installation.

INSTALLATION	STATE	Risk Assessment			
		Area 1	Area 2	Area 3	Area 4
Fort McClellan	Alabama	H	H	H	H
Fort Greely	Alaska	M	M	H	L
Fort Chaffee	Arkansas	M	L	M	H
Branch US Disciplinary Barracks Lompoc	California	L	M		
East Fort Baker	California	H	L	H	
Oakland Army Base	California	L	H		
Rio Vista ARC	California	M	H		
Sierra Army Depot	California	H	L		H
Fitzsimons Army Medical Center	Colorado	L	L		
Stratford Army Engine Plant	Connecticut	M			
Big Coppitt Key	Florida	M	L		
Savanna Army Depot Activity	Illinois	H	L		H
Fort Holabird	Maryland	M	M	M	
Fort Ritchie	Maryland	L	L	M	
Hingham Cohasset	Massachusetts	L	L		
Sudbury Training Annex	Massachusetts	H	M	H	
Detroit Arsenal	Michigan	H	L		
Fort Missoula	Montana	L	L	M	
Bayonne Military Ocean Terminal	New Jersey	M	L		
Camp Kilmer	New Jersey	M		H	
Camp Pedricktown	New Jersey	H		H	
Fort Dix	New Jersey	H	L	H	M
Bellmore Logistics Activity	New York	L	M		
Fort Totten	New York	L	M		
Seneca Army Depot	New York	H	L		H
Recreation Center #2, Fayetteville	North Carolina	H	M		
Kelly Support Center	Pennsylvania	M	H		
Letterkenny Army Depot	Pennsylvania	M	L		H
Fort Buchanan	Puerto Rico	L	L		
Red River Army Depot	Texas	H	L		H
Fort Pickett	Virginia	H	L	M	
Camp Bonneville	Washington	M		H	

Table 10. 'Risk:' risk assessment for each area on each installation.
A blank indicates the area does not exist on the installation.

The second part of the sheet 'Risk' allows the user to fix the minimum clean-up level for the three risk categories. The user might change these numbers, but he or she must ensure their range is between 0.0 and 1.0.

Risk Values

Category	High	Medium	Low
Level	0.9	0.6	0.3

Table 11. Default percentage for minimum clean-up levels based on risk assessment. This is only for flexible options.

The sheets 'BVALUE, SBVALUE, MINLEVEL and MININIT' produce the appropriate matrices needed by the model described in Chapter III. MS-EXCEL automatically determined their values based on the input of the previously described worksheets.

The remaining sheets 'UBUDGET, LBUDGET, SCOST and MINCOST' contain data provided by BRACO or based on data provided by BRACO. The sheet 'LBUDGET' provides data based on the upper budget limit 'UBUDGET' (The default value of 5% of the upper budget limit is used here).

C. IMPLEMENTATION OF MATHEMATICAL MODEL

BAEC is generated using the General Algebraic Modeling System (GAMS) Version 2.25.087 and OSL Version 2 solves the problem [GAMS Development Corporation, 1995].

The implementation is done on an IBM compatible personal computer with 40 Megabyte of random access memory and a 90 Megahertz Intel Pentium central processor. The elastic mixed integer linear program BAEC consists of approximately 28,000 equations, 92,000 non-zero coefficients, 20,000 single variables and 13,000 binary variables for the instance generated using the data previously described. The solution time is approximately 100 minutes.

The same model is also solving on an RS 6000 Model 590 workstation using the OSL Version 2 solver and CPLEX 3.0. The solve times for the mixed integer linear programs are 24 minutes and 8 minutes respectively.

D. DATA OUTPUT

The result for the above problem is produced for use in a MS-EXCEL spreadsheet called 'RESULTS.XLS'. The GAMS model writes a solution file called 'RES.PRN'. This file has to be opened via MS-EXCEL; converted to a MS-EXCEL file; saved as 'RES.XLS' in the same subdirectory as the 'RESULTS.XLS' file; and then opened as 'RESULTS.XLS' in MS-EXCEL. After recalculating the workbook, the results can be viewed in several worksheets. Each of the 32 military installations has its own worksheet providing information about the six year (1996 - 2001) upper budget limit, the lower budget limit, the minimum cost and the budget allocation determined by BAEC for each clean-up action. Table 12 shows an example of this presentation for one installation.

		Fort McClellan, Alabama				
	Dollars in (000)					
	1996	1997	1998	1999	2000	2001
Asbestos Removal	0	0	3243	0	0	0
USTS Removal	0	300	2714	1140	770	795
UXO Removal	0	0	0	8245	7164	0
Removal Actions	0	0	6934	0	0	0
PCB Abatement	0	50	2525	555	595	660
LBP Abatement	480	620	2842	405	430	470
Soil Remediation	2400	2470	2540	4222	1475	1535
Radiation Remediation	0	0	2489	0	0	0
Chemical Remediation	0	0	5196	0	0	0
Garbage Disposal	0	488	4627	558	0	0
Hazardous Waste Disposal	0	0	2672	0	0	0
Septic/Medical Disposal	0	0	1223	0	0	0
Building Clean-up	0	155	1597	0	0	0
Landfill Clean-up	0	0	4569	0	0	0
Water Treatment	50	60	3880	430	460	490
Lead Contamination	0	0	4366	0	0	0
Area Closures/Fencing	0	63	4604	0	0	0
Remedial Investigation/Surveys	0	0	2150	9405	0	0
Minimum Costs	168	213	180	174	169	164
Total	3098	4419	58351	25134	11063	4114
Upper Budget Limit	8425	20921	69406	428	299	179
Lower Budget Limit	421	1046	3470	21	14	8

Table 12. BAEC results available for a single installation viewed in MS-EXCEL. The budget allocation determined by BAEC is presented for each clean-up action. Furthermore the minimum costs, the total allocated budget and the upper and lower budget limits are shown for each year.

Below this numerical presentation the user finds a chart (see Figure 4), that shows the same data on a simple bar chart.

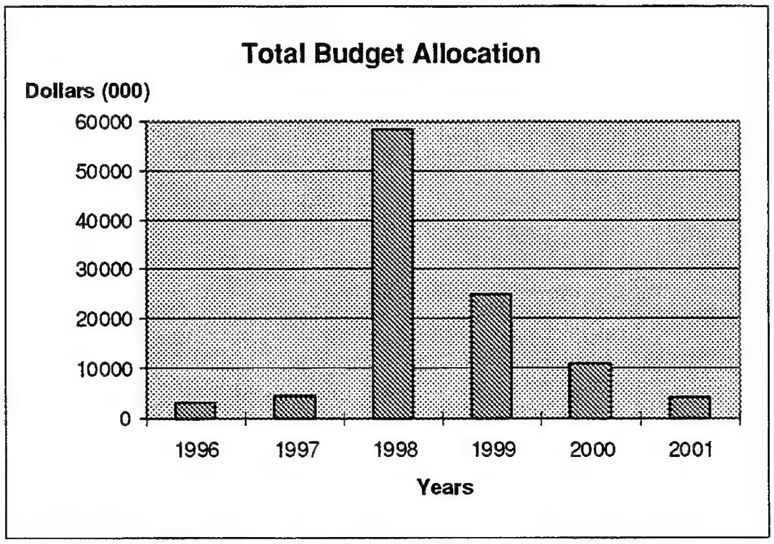

Figure 4. Column chart presentation of the budget allocation for a particular installation.

Besides the 32 worksheets, which summarize the individual results for each military installation, a summary worksheet provides the overall budget allocation for each military installation and all time periods (see Table 13) and a bar chart.

TOTAL BUDGET ALLOCATION

Dollars (000)

INSTALLATION	STATE	1996	1997	1998	1999	2000	2001	Total Budget
Fort McClellan	Alabama	3098	4419	58351	25134	11063	4114	106180
Fort Greely	Alaska	303	2429	2560	760	755	469	7276
Fort Chaffee	Arkansas	7636	11523	7275	86	0	0	26520
Branch US Disciplinary Barracks Lompoc	California	0	263	3488	3112	0	0	6863
East Fort Baker	California	444	2218	91	29	0	0	2782
Oakland Army Base	California	423	463	4723	3946	3685	3723	16963
Rio Vista ARC	California	493	1799	0	0	0	0	2292
Sierra Army Depot	California	1290	2192	20680	17382	4543	7145	53231
Fitzsimons Army Medical Center	Colorado	394	658	462	5132	2148	1904	10699
Stratford Army Engine Plant	Connecticut	80	125	1912	12694	6616	2763	24190
Big Coppitt Key	Florida	357	1209	0	0	0	0	1566
Savanna Army Depot Activity	Illinois	7066	10283	17317	92012	77344	50641	254663
Fort Holabird	Maryland	215	53	0	0	0	0	268
Fort Ritchie	Maryland	341	199	1862	1305	1446	232	5385
Hingham Cohasset	Massachusetts	419	259	202	819	555	0	2254
Sudbury Training Annex	Massachusetts	706	2323	401	5146	0	0	8576
Detroit Arsenal	Michigan	113	1002	8519	746	22405	1993	34777
Fort Missoula	Montana	275	748	250	1147	0	0	2420
Bayonne Military Ocean Terminal	New Jersey	179	137	1968	5151	2613	1080	11128
Camp Kilmer	New Jersey	575	3236	2135	0	0	0	5946
Camp Pedricktown	New Jersey	1758	6735	3935	0	0	0	12428
Fort Dix	New Jersey	732	2552	211	0	0	0	3495
Bellmore Logistics Avtivity	New York	104	1391	1508	2050	0	0	5054
Fort Totten	New York	202	682	6934	8668	0	0	16486
Seneca Army Depot	New York	1454	3467	21930	19790	34433	9448	90523
Recreation Center #2, Fayetteville	North Carolina	445	652	243	0	0	0	1340
Kelly Support Center	Pennsylvania	501	1408	1423	0	0	0	3332
Letterkenny Army Depot	Pennsylvania	335	1705	18179	31129	22775	16476	90598
Fort Buchanan	Puerto Rico	155	839	1701	3787	0	0	6482
Red River Army Depot	Texas	256	933	5619	1672	1561	744	10784
Fort Pickett	Virginia	240	645	5718	9804	3158	486	20050
Camp Bonneville	Washington	812	3952	4003	0	0	0	8767
Total Sum by Year		31400	70500	203600	251500	195100	101217	853317
Available Budget		31400	70500	203600	251500	195100	163400	915500

Table 13. Summary of the budget allocation for all installations.

To obtain detailed information about particular budget allocations, 'RES.XLS' contains detailed budget allocations for each clean-up action (see Table 14).

Indices			1996	1997	1998	1999	2000	2001
I1	J1	K1	0	0	1860.47	0	0	0
I1	J1	K2	0	300	320	330	350	360
I1	J1	K3	0	0	0	2259.22	1440.25	0
I1	J1	K4	0	0	1813.19	389.29	0	0
I1	J1	K5	0	50	60	75	85	100
I1	J1	K6	100	120	130	145	155	170
I1	J1	K7	550	600	660	720	800	880
I1	J1	K8	0	0	394.7	0	0	0
I1	J1	K9	0	0	1655.07	0	0	0
I1	J1	K10	0	0	1600.5	0	0	0
I1	J1	K11	0	0	875.16	0	0	0
I1	J1	K12	0	0	628.09	0	0	0
I1	J1	K13	0	0	1596.53	0	0	0
I1	J1	K14	0	0	1627.29	0	0	0
I1	J1	K15	50	60	75	90	100	110
I1	J1	K16	0	0	1042.85	0	0	0
I1	J1	K17	0	0	66.15	0	0	0
I1	J1	K18	0	0	2150.21	0	0	0
I1	J2	K1	0	0	1382.2	0	0	0
I1	J2	K2	0	0	793.8	0	0	0
I1	J2	K3	0	0	0	0	0	0
I1	J2	K4	0	0	1453.65	0	0	0
I1	J2	K5	0	0	2025.18	0	0	0
I1	J2	K6	0	0	2071.82	0	0	0

Table 14. Excerpt from the MS-EXCEL file called 'RES.XLS' providing detailed budget allocation for each clean-up action in dollars (000).

E. COMPUTATIONAL RESULTS

The assumed test data provides a budget allocation with several interesting characteristics. The objective function value is about 16,852. Examining the three objective function terms shows, that the overall benefit for clean-up (Z1) obtains a value of 37,522, whereas the second term (Z2), which encourages spending in more populated areas has a value of 0.11. The difference between the total objective function value (16,852), the benefit (37,552) and the population term (0.11) is the penalty for violating individual installation budgets (Z3). The results show the model influences spending based on population. As an example, the Branch US Disciplinary Barracks, Lompoc in California with a low population spends only $6,863,150 of its six year available budget of $12,900,000. Whereas Detroit Arsenal, Michigan spends $34,776,610, about 95 % of its

$36,710,000 budget. Table 15 shows violations by each installation above its available budget limit.

Installation	1996	1998	1999	2000	2001
Fort McClellan			24706.03	10764.32	3935.00
Fort Greely			194.68	434.99	143.75
Fort Chaffee			86.00		
USDB Lompoc			597.04		
East Fort Baker		91.00	29.00		
Oakland AB				536.07	1610.99
Sierra AD				307.60	4056.98
Fitzsimons					1303.78
Savanna AD	4435.00		16914.20	23398.79	4901.37
Fort Ritchie			563.14	1357.88	143.79
Hingham		152.00	769.14	545.33	
Sudbury		351.00	5095.60		
Detroit Arsenal			336.00	21994.61	1582.53
Fort Missoula			146.74		
Bayonne				1490.33	1009.62
Bellmore			1650.23		
Fort Totten			1522.73		
Seneca AD			2408.09	30198.47	6359.86
Kelly Support		23.69			
Letterkenny AD			4108.78		11405.89
Fort Buchanan			2581.97		
Red River AD				1389.07	572.00
Fort Pickett			7032.61	2996.55	322.00

Table 15. Violations on each installation's upper budget limit in dollars (000).

The results indicate most violations to the individual installation available budget occur in the last three years. This is most likely due to hypothetical cost estimates. Violations did not occur on relatively small installations with low environmental clean-up costs, like Big Coppitt Key, Florida or Fort Holabird, Maryland.

Figure 5a and Figure 5b compare the budget allocations for Seneca Army Depot, New York (a large installation) and Camp Kilmer, New Jersey (a small installation).

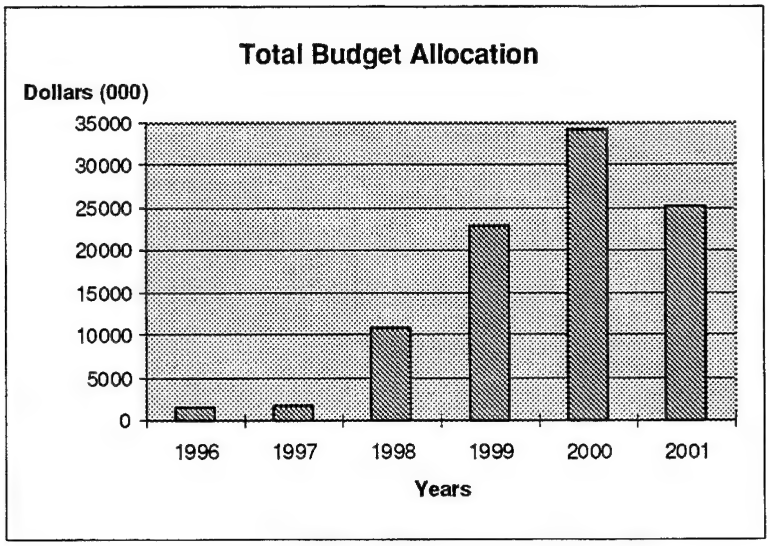

Figure 5a. Budget allocation for Seneca Army Depot.

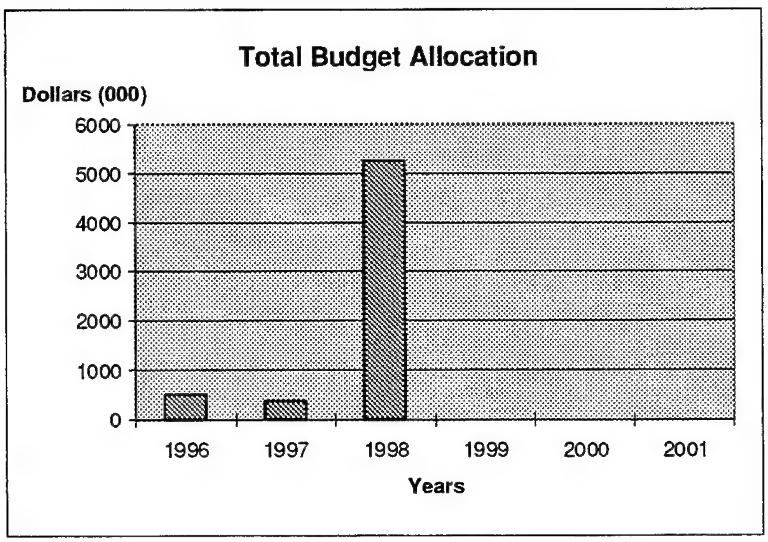

Figure 5b. Budget allocation for Camp Kilmer.

The results for Seneca Army Depot indicate, that its available budget is not enough in the last three years. Starting in 1999 the allocated budget is higher than the available budget. Interestingly, the cause of these high costs are the significantly high spending on remedial investigation/surveys in the years 1999 to 2001. All other clean-up actions either are finished before 1999 or have comparably small costs. Another observation is the budget allocation for asbestos removal and removal actions (i.e., fuel tank removal). After starting clean-up in 1998, both actions are not active in 1999 removal actions are not

active in 2000. But both actions are activated again in 2000 and 2001 respectively. These 'clean-up gaps' happen in different areas. (In other words, asbestos removal is started and finished on one or more areas in 1998 and in 2000 the same clean-up action is started and finished on different areas). Actually the solution file 'RES.XLS' obtains detailed results for these clean-up actions and shows the detailed budget allocation for each area. In this case, the military area has asbestos removal in 1998 and the housing area performs it in 2000.

A close look at the total budget allocation for all 32 installations indicates the complete amount of available budget is spent in the first five years. In 2001 only 63 % of the total budget is used indicating clean-up is finishing early to obtain a higher benefit. Furthermore it indicates, that time, clean-up actions and the related risk assessment have a high impact on budget allocation. About 93.2 % of the total available budget is used. The Army Depots and Fort McClellan, Alabama are the main budget consumers.

F. SENSITIVITY ANALYSIS

To further demonstration of the model's capabilities, a sensitivity analysis is performed. Several characteristics of the mathematical model are of special interest. One important attribute is the robustness of the benefit value model to changing the subjective weight factors k_i. Three cases are considered; small changes of the factors indicating the highest weight factor of the clean-up actions and the reuse possibilities respectively and extreme changes indicating a high preference to the time factor. Table 16 shows the setup of the weight factors for the three cases compared to the default setting.

Weight Factors	Default Case	Case 1	Case 2	Case 3
activity	0.1	0.05	0.05	0.001
reuse	0.4	0.3	0.6	0.001
population	0.05	0.05	0.05	0.001
community assessment	0.1	0.05	0.05	0.001
clean-up action	0.3	0.5	0.2	0.001
time	0.05	0.05	0.05	0.995

Table 16. Settings of the weight factors for the three different cases.

To examine the impact of B_i values, three cases are considered: doubling the value of B_5 (clean-up actions and options); halving the value of B_5; and increasing the value of B_6 (time) tenfold.

The next step examines the population weight factor (POPWT). It is increased twice (from its default of 0.001 to 0.1 and 10.0).

To examine the effect of the penalties for violating the installations' budget constraints for the upper budget limit and the lower budget limit are set up to values close to zero (0.0000001).

The last examination and analysis of the impact on the budget allocation is to change the budget itself. Four cases are considered: increasing the yearly available budget by $5 millions per year, decreasing the budget by the same amount per year, increasing the available budget by $10 millions for years 1997 and 1998 and decreasing the budget by the same amount for the same years. The years 1997 and 1998 are considered because they reflect the time period where better data are available. Furthermore the previous results indicate that these two years seem to be key years.

For all parts of this sensitivity analysis, the budget allocation for the Seneca Army Depot is presented and overall results are shown wherever they provide further insight.

Changing the weight factors with a high factor for the clean-up actions (Case 1) causes only minor changes to the budget allocation for Seneca Army Depot. This indicates that small changes of the weight factor may not have a huge impact on the budget for a single installation for the data considered. Similar results at the other installations verify this result. Looking at the total budget, total allocated budget for all installations increases for the year 1996 in comparison to previous results. For the remaining years it remains constant or decreases. This indicates the clean-up action is time related. Weighting the clean-up actions higher allocates more money in the first years. A similar result is obtained by shifting the main emphasis on the weight factor for the reuse possibilities (Case 2), with the exception that the changes are smaller than before. Weighting the time (Case 3) extremely high and the other factors very low has no impact at all. In this case the other key factors are weighted so low, that the time factor alone does not have enough impact on the benefit value to obtain significant changes on the budget allocation. Figures 6a and 6b illustrate the budget allocation for Seneca Army Depot and the total budget allocation for the three different cases in comparison to the default setting over the six year period.

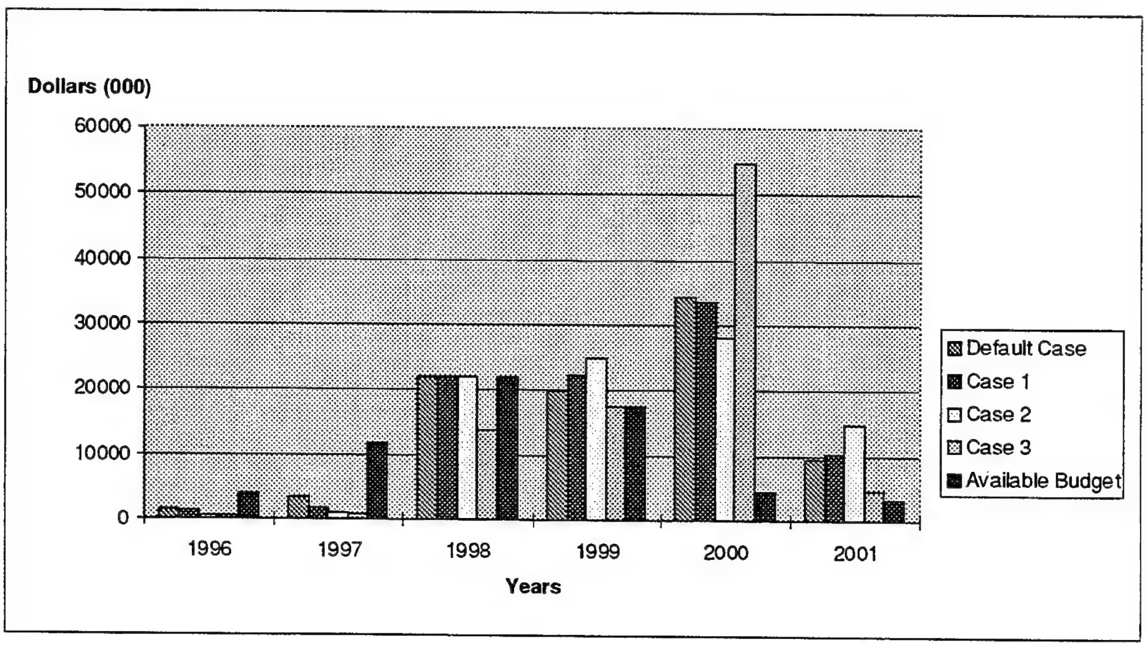

Figure 6a. Budget allocation for Seneca Army Depot with different weight factors. Case 1 indicates a high factor for clean-up actions, Case 2 represents a high factor for reuse and Case 3 indicates a high time factor (see Table 16).

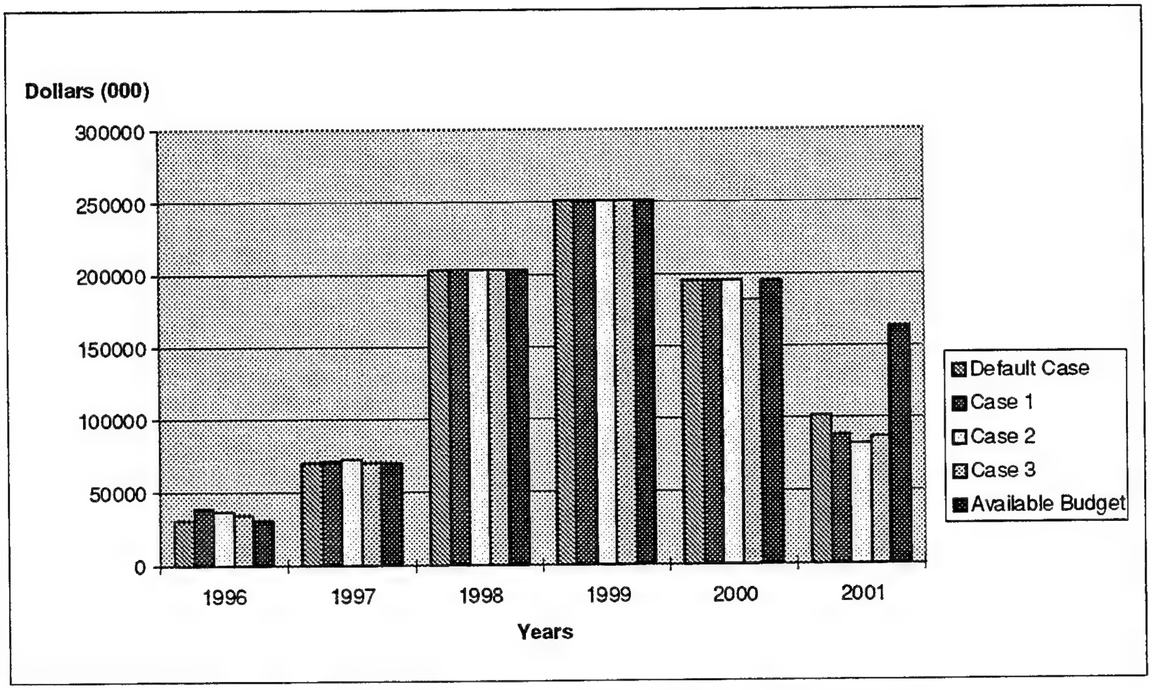

Figure 6b. Total budget allocation with different weight factors.

Doubling the values B_5 for clean-up actions (Value Case 1), halving these values (Value Case 2) or increasing the value B_6 for time (Value Case 3) produces results similar to those obtained when changing the weight factors except in years 2000 and 2001. Doubling the values B_5 causes the budget allocation to increase in the first few years and to decrease in the last two years. For Seneca Army Depot doubling the values decreases the budget for all years except years 1996 and 2001. In 1996 it remains constant, whereas in 2001 the allocated budget increases significantly. Taking a closer look at the results for Seneca Army Depot indicates most clean-up actions are supposed to start in 1998 or later. The remedial investigations and surveys (starting in year 2000) are the source for this high budget allocation in 2001.

Halving the values of B_5 obtains similar results except for a significant decrease to the budget allocated in 2001 and minor increases in years 1999 and 2000. This indicates it is more convenient to allocate as much money as possible in the years prior to 2001 in order to obtain a higher benefit.

Changing the value for B_6 for time by a factor of ten obtains similar results as Value Case 2 for Seneca Army Depot. The total budget allocation across all installations

shows a different behavior. A huge amount of money is allocated in the year 2001. The budget for the first years is fixed at its upper limit or slightly above and more money is allocated in the last year. An unusual observation is that year 2000 does not receive as much money as possible and significantly less than the year 2001, whereas in the year 2001 the available budget is exceeded. Further examination on other installations shows, that significantly time related and highly beneficial clean-up actions requiring a funding stream are chosen on installations with high risk assessment (e.g., Fort McClellan, Sierra Army Depot or Letterkenny Army Depot). These actions cause the extremely high budget allocation in the last year. Figures 7a and 7b show the budget allocation for Seneca Army Depot and the total budget allocation respectively.

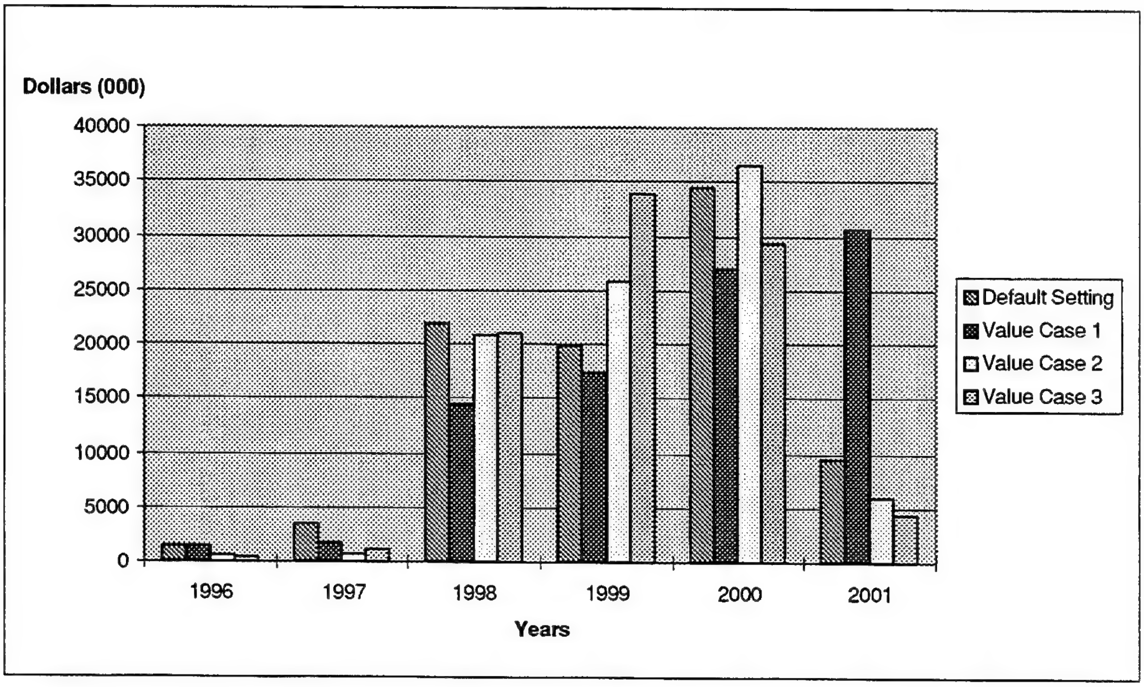

Figure 7a. Budget allocation for Seneca Army Depot with different value assignments. Value Case 1 represents doubling the values for B_5, Value Case 2 indicates halving these values and Value Case 3 represents increasing the values for B_6.

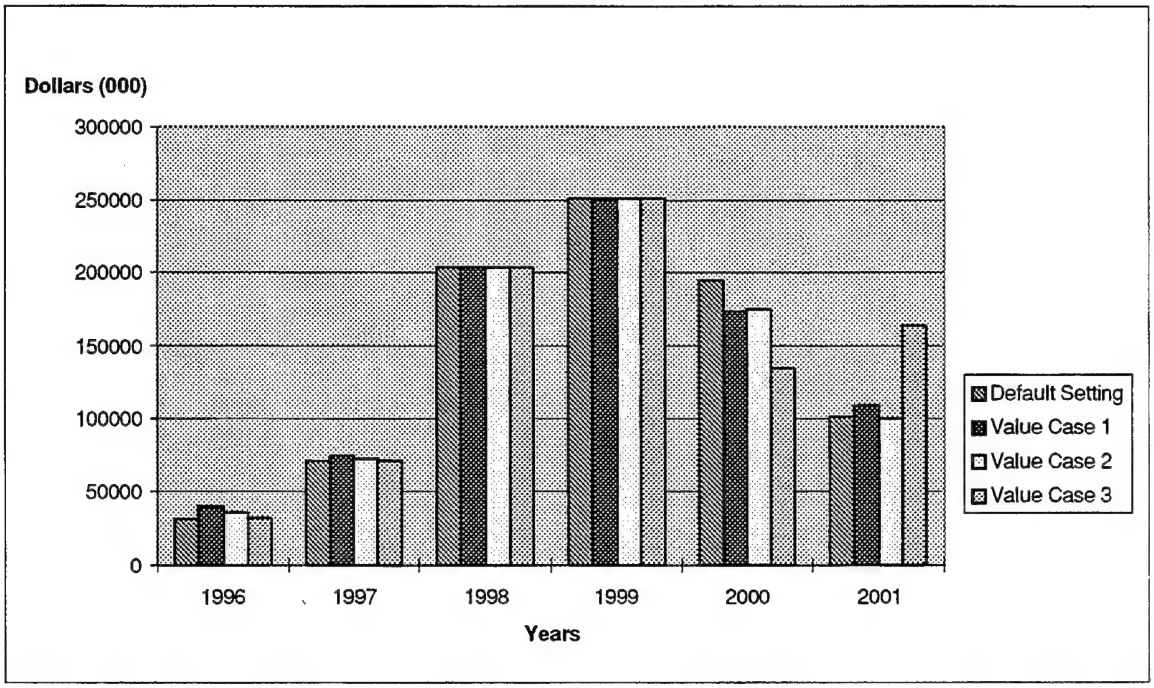

Figure 7b. Total budget allocation with different value assignments.

Increasing the population weight factor could lead to a small decrease in the budget allocation for installations with a low population around the installation. As an example Camp Bonneville, Washington (population: 500) realizes a slight decrease.

Setting the penalties for violating the upper and lower budget constraint close to zero (0.0000001), results in allocating the maximum amount in every year. For example, the budget for Seneca Army Depot installation is allocated to those clean-up actions that start in later years with a high benefit. In the first three years the upper budget limit is neither exceeded nor reached, but in the last three years (1999 to 2001) the budget is exceeded significantly due to extremely low penalties for violating the budget constraints. This observation applies similarly to all other installations. Table 17 and Figure 8 illustrate these results for Seneca Army Depot.

Seneca Army Depot, New York

Dollars in (000)

	1996	1997	1998	1999	2000	2001
Asbestos Removal	0	0	0	2206.32	0	0
USTS Removal	0	0	870	1637.85	915	365
UXO Removal	0	0	693.47	1262.74	0	0
Removal Actions	0	0	1705.46	1496.11	0	0
PCB Abatement	0	0	380	1561.99	398	0
LBP Abatement	400	415	435	880.72	463	483
Soil Remediation	145	395	415	991.84	452	470
Radiation Remediation	0	0	0	2069.38	0	0
Chemical Remediation	0	0	607.48	1403.39	0	0
Garbage Disposal	0	0	1886.61	0	0	0
Hazardous Waste Disposal	0	0	0	1972.25	0	996.78
Septic/Medical Disposal	0	0	467.46	1611.76	0	0
Building Clean-up	0	0	513.77	431.33	0	0
Landfill Clean-up	0	0	0	1154.38	0	1030.34
Water Treatment	480	500	1401.8	536	554	570
Lead Contamination	0	0	533.61	1375.26	0	0
Area Closures/Fencing	0	0	543.75	1943.76	0	0
Remedial Investigation/Surveys	0	0	0	0	31155.85	20995.09
Minimum Costs	429	382	297	323	265	243
Total	1454	1692	10750.41	22858.08	34202.85	25153.21
Upper Budget Limit	3871	11492	21930	17382	4235	3088
Lower Budget Limit	193	574	1096	869	211	154

Table 17. Detailed budget allocation for Seneca Army Depot with low penalties for violating the budget constraints.

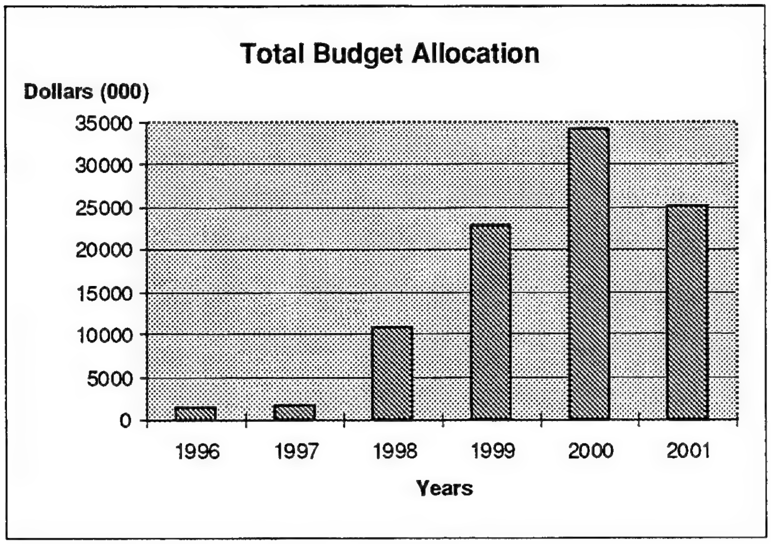

Figure 8. Total budget allocation for Seneca Army Depot with low penalties for violating the budget constraints.

Increasing the total budget available by an amount of $5,000,000 per year (Level 1) leads to a higher allocation of the available budget at Seneca Army Depot but not for every year. In 1998, 2000 and 2001 the budget allocation decreases slightly and in the remaining years it increases. These changes can be explained by looking at the clean-up actions. The most significant changes are received by the hazardous waste disposal, asbestos removal and remedial investigations in 1999. A huge amount of money is allocated to these clean-up actions in this year whereas the default budget level does not allocate any money or just a small amount of money for these actions in that year. Therefore the high benefit value for these clean-up actions is responsible for this budget allocation.

Decreasing the total budget available by $5,000,000 per year (Level 2) shows a different result: year 2001 shows a significantly high increase to its allocated budget. In this case the available budget is allocated more evenly in all six years. The same observation is valid for the total budget.

Increasing the total budget by $10,000,000 in 1997 and 1998 (Level 3) leads to a decreasing budget allocation in the following years. This applies to Seneca Army Depot and the total budget allocation as well. Decreasing the budget level by the same amount in

the same years (Level 4) decreases all budget levels at Seneca Army Depot and the total budget allocation as well except for the last year (2001). In this year the budget allocation is about four times higher than the default budget level. Looking at the total budget allocation it is obvious that the big installations (e.g., Fort McClellan and the Army Depots) receive a large amount of money in this last year to guarantee the minimum clean-up levels are satisfied. Violations of the budget constraints are tolerated to obtain this goal. Figure 9 summarizes the different results obtained by different budget levels for Seneca Army Depot.

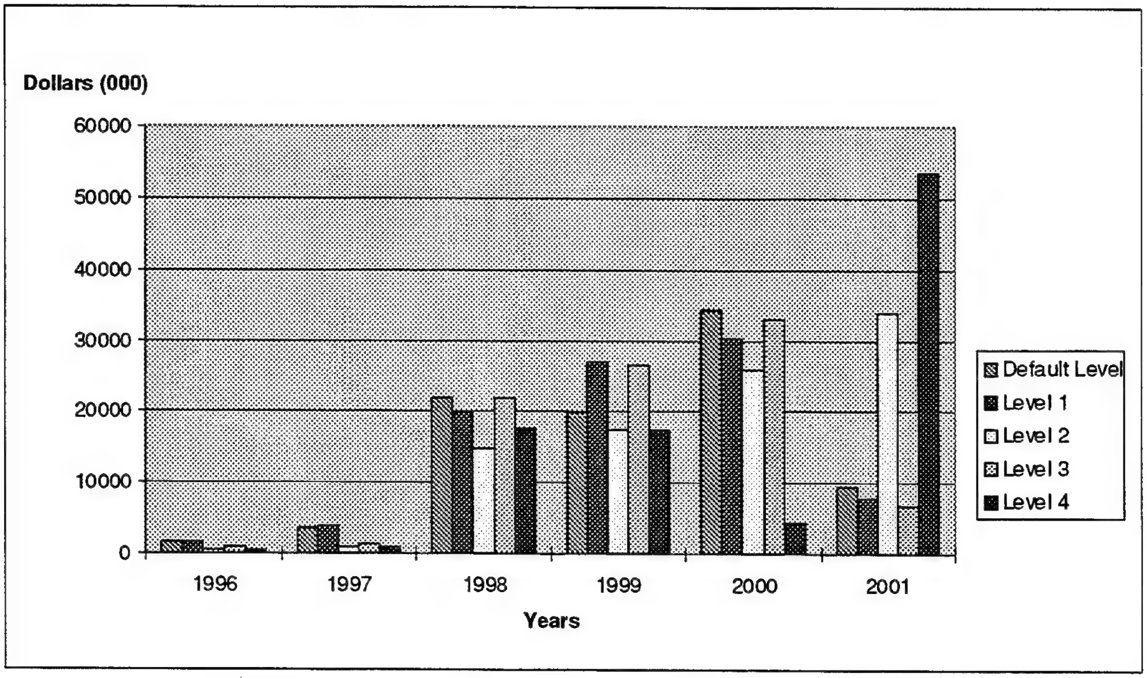

Figure 9. Budget allocation for Seneca Army Depot with different budget levels. Level 1 indicates an increase of the total budget of 5 million dollars per year; Level 2 indicates a decrease of the same amount per year; Level 3 indicates an increase of 10 million dollars in years 1997 and 1998; and Level 4 indicates a decrease of 10 million dollars in years 1997 and 1998.

At last, the expressiveness of the benefit value is analyzed. As the objective function states the value is divided in three parts, the term that maximizes benefit (Z1), the term that encourages more spending on highly populated areas (Z2) and the part that minimizes the penalties for violating the budget constraints (Z3). Table 19 shows all benefit values obtained by the previously described changes within the model.

Change	Benefit	Z1	Z2	Z3
Default Case	16851.78	37521.52	0.11	20669.63
Weight Factor Case 1	25885.61	46646.77	0.11	20761.06
Weight Factor Case 2	16616.14	36301.56	0.11	19685.31
Weight Factor Case 3	-14102.12	4125.08	0.11	18227.10
Low Penalties	40685.03	40685.19	0.11	0.04
Budget Level 1	18021.01	37831.89	0.11	19810.77
Budget Level 2	13202.22	36959.49	0.11	23757.16
Budget Level 3	18761.75	37752.66	0.11	18990.80
Budget Level 4	12583.78	37162.95	0.11	24579.07
Value Case 1	37534.73	58832.31	0.11	21297.47
Value Case 2	7320.29	26511.95	0.11	19191.55
Value Case 3	17621.05	38971.15	0.11	21350.00
POPWT Case 1	16879.60	36969.37	10.72	20070.05
POPWT Case 2	15502.79	37136.37	1073.06	20560.52

Table 18. Summary of all benefit values obtained during the analysis.

The maximum benefit value (Z1) is obtained by doubling the values for the clean-up actions whereas the minimum value of Z1 is obtained by assigning a high weight factor to the time criterion. This is an indicator of the importance of the clean-up action as a key factor for the overall benefit. It is interesting that Z2 is almost constant and very low except in those cases, where the population weight factor is increased. This indicates the constant budget allocation based on the population weight factor. Decreasing the penalties to zero results in a significantly low value for Z3 as expected. All these values reflect those changes made directly or indirectly on the benefit value model. A highest benefit value does not indicate the best budget allocation and a low benefit value does not necessarily

indicate a bad budget allocation. It is the decision maker's task to fit the available budget to each installation guided by this model. The benefit value is not an exact measure, because of its subjectivity but the linear benefit model shows robustness and stability due to significant changes to the budget allocation.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis shows how a linear integer programming model (BAEC) can help a decision maker with budget allocation for environmental clean-up. A simple linear value model to measure benefit facilitates a relatively straightforward allocation of yearly budgets. BAEC has been designed to run on a personal computer in a user friendly environment. The spreadsheet interface allows easy data input and analysis of model output.

B. RECOMMENDATIONS

The BAEC computer model should be considered a prototype. The mathematical model and its implementation are general enough that only few changes should be needed after receiving real data. The value model can be easily changed via the spreadsheet input procedure to accommodate different decision makers.

Continuing research should consider restricting particular clean-up actions in relation to when other actions are completely finished. Research should be conducted to examine the meaning of the benefit value in terms of money. Perhaps a model might be introduced to determine the amount of money returned to the government based on the benefit (new jobs, more taxpayers, renting charges for buildings etc.). However, one should not forget that this model is only a tool to provide guidance to the decision maker in allocating yearly budgets.

LIST OF REFERENCES

Army Times 1995, "Guide to Military Installations in the U.S.," (November).

Bandy, J.T.; Marlatt, R.M.; Lang, L.E.; Poon, C.P.C.; Skov, K.; Prakash, T.M. 1987, "Evaluation of Grease Management Alternatives for Army Wastewater Collection and Treatment Systems," US Army Corps of Engineers, Construction Engineering Research Laboratory, Technical Report N 87/15.

Bloemhof-Ruwaard, J.M.; Van Beek, P.; Hordijk, L.; Van Wassenhove, L.N. 1995, "Interactions between Operational Research and Environmental Management," *European Journal of Operational Research*, Vol. 85, pp. 229-243.

Brooke, A.;Kendrick, D.;Meeraus, A. 1992, "GAMS: A User's Guide, Release 2.25," The Scientific Press, South San Francisco, CA.

Corbett, C.J.; Debets, F.J.C.; Van Wassenhove, L.N. 1995, "Decentralization of Responsibility for Site Decontamination Projects: A Budget Allocation Approach," *European Journal of Operational Research*, Vol. 86, pp. 103-119.

Delta Research Corporation 1996, "Remedial Action Cost Engineering and Requirements System, RACER Release 3.2, User Manual," Niceville, FL.

Department of Defense 1990,"Civilian Reuse of Former Military Bases, Summary of Completed Military Base Economic Adjustment Projects, 1961-1990," Washington, DC.

Evinger, W.R. 1991, "Directory of Military Bases in the U.S.," The Oryx Press, Phoenix, AZ.

GAMS Development Corporation 1995, "GAMS - Installation and System Notes," Washington, DC.

Greenberg, H.J. 1995, "Mathematical Programming Models for Environmental Quality Control," *Operations Research*, Vol. 43, No. 4 (July-August), pp. 578-622.

Haggerty, M.J. 1992, "The Time is Now," *Airman*, Vol. 36, No. 4 (April), pp. 22-23.

Keeney, R.L. 1992, "Value-Focused Thinking: A Path to Creative Decision Making," Harvard University Press, Boston, MA.

Loucks, D.P.; ReVelle, C.S.; Lynn, W.R. 1967, "Linear Programming Models for Water Pollution Control," *Management Science*, Vol. 14, No. 4 (December), pp. 166-181.

Marshall, K.T.; Oliver, R.M. 1995, "Decision Making and Forecasting," McGraw-Hill, Inc., New York.

MICROSOFT® Corporation 1994, "Microsoft EXCEL 5.0, User's Guide".

Office of the Deputy Under Secretary of Defense 1994, "The Relative Risk Site Evaluation Concept," Washington, DC.

President's Economic Adjustment Committee 1978, "Planning Civilian Reuse of Former Military Bases," (September), Washington, DC.

President's Economic Adjustment Committee 1990, "Civilian Reuse of Former Military Bases," (June), Washington, DC.

ReVelle, C.S.; Cohon, J.; Shobrys, D. 1991, "Simultaneous Siting and Routing in the Disposal of Hazardous Wastes," *Transportation Science*, Vol. 25, No. 2 (May), pp. 138-145.

ReVelle, C.S.; Ellis, J.H. 1994, "Models for Water and Air Quality Management," *Handbooks in OR & MS*, Vol. 6, pp. 365-401.

Shellner, E. 1992, "A Clean Sweep," *Airman*, Vol. 36, No. 4 (April) pp. 36-38.

United States General Accounting Office, National Security and International Affairs Division 1994, "Environmental Cleanup," (November), Washington, DC.

United States Defense Base Closure and Realignment Commission 1995, "Report to the President," Washington, DC.

U.S. Census Bureau, "http://www.census.gov," accessed in December/1995.

U.S. Gazetteer, "http://www.census.gov/cgi-bin/gazetteer," accessed in December/1995.

Utton, A.E.; Henning, D.H. 1973, "Environmental Policy," Praeger Publishers, New York.

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